Two alterations to be [illegible] in proof

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# Reply to Fellows and Stapp on "Bell's Theorem and the Foundations of Quantum Physics" [Am. J. Phys. 53, 306 (1985)]

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Recently Fellows[1] has argued that Stapp's[2] nonlocality proof "fails due to an implicit assumption of realism". Stapp's reply[3] avoids directly addressing most of Fellows' points and instead gives a detailed explication of the logical distinction between the words 'could' and 'would'. The purpose of this note is to adequately rebut each of Fellows' criticisms in turn and point out the irrelevance of Stapp's reply.

Fellows begins by objecting to the "phrasing" of Stapp's four locality conditions singling out, as an example, the condition summarized by the equation $r_{Ai}(\hat{\lambda}_b) = r_{Ai}(\hat{\lambda}_a)$ which he finds "...troubling, for it suggests that a particle can in some way be detected by both setup a and setup b." Given that $r_{Ai}(\hat{\lambda}_a)$ [respectively $r_{Ai}(\hat{\lambda}_b)$] symbolizes the measured value of the A-particle's spin (of the $i^{th}$ particle pair) along the direction $\theta_A'$ (which can be $\pm 1$) when the distant B-particle detector is set to the direction $\theta_B'$ [respectively $\theta_B''(\neq \theta_B')$], this condition amounts to asserting the truth of the counterfactual conditional 'If the distant B-detector had been set to $\theta_B''$, then the A-measurement would have yielded $r_{Ai}(\hat{\lambda}_b)$, such that $r_{Ai}(\hat{\lambda}_b) = r_{Ai}(\hat{\lambda}_a)$' (CC1) in a world w where the B-detector is set to $\theta_B'$ and the A-measurement yields $r_{Ai}(\hat{\lambda}_a)$. Assertion CC1 forces us to conceive of an alternative state of affairs (or 'world') to that which is realized in w (viz., one in which the distant B-detector is set differently), so logically it functions in the same way as does a conditional like 'If John had set the light switch to 'ON', then the light would have gone on'(CC2) made under an actual state of affairs (or in the actual 'world') in which John leaves the light switch set to 'OFF'. In no way does CC2 suggest or imply, as Fellows would have it, that the light can be both on and off, for in the actual world it is off and under the conceived state of affairs (or 'world') that CC2 leads us to imagine, it is on. This does not imply that there is a single world in which it is both on and off! (In logician's terminology such an implication commits the modal

#1 logical fallacy $(\Diamond A \wedge \Diamond \cancel{B}\,{\sim}A) \supset \Diamond(A \wedge \cancel{B}\,{\sim}A)$.) The analogous point holds for CC1[4].

Fellows continues by objecting to Stapp's use of the product expression (PE) $r_{Bi}(\hat{\lambda}_a) r_{Bi}(\hat{\lambda}_b)$ in his deduction of a contradiction with the predictions of quantum mechanics (QM). Fellows' only argument is that in PE "...one sees that the spin projection of the $i^{th}$ particle entering detector B

must be simultaneously measured along two distinct axes, corresponding to the different orientations of detector B in setup a and b. [italics mine]" But Fellows is misled by PE's notation for this expression is nothing but the product $r_{Ai}(\hat{\lambda}_d)r_{Bi}(\hat{\lambda}_d)$ [Sec. IV, Eq. 3(d)] plus the three locality conditions $r_{Ai}(\hat{\lambda}_d) = r_{Ai}(\hat{\lambda}_c)$, $r_{Bi}(\hat{\lambda}_d) = r_{Bi}(\hat{\lambda}_b)$, $r_{Bi}(\hat{\lambda}_c) = r_{Bi}(\hat{\lambda}_a)$ [Sec. V, Eqs. (4d), (4c), and (4b)] and the equation $r_{Ai}(\hat{\lambda}_c) = - r_{Bi}(\hat{\lambda}_c)$ [Sec. VI, Eq. (5)] (expressing the strict anti-correlation predicted by QM for the detectors set to $c=(\theta_A'', \theta_B')=(45°,45°)$). The locality conditions correspond to counterfactual conditionals like CC1 which equate measured spin values registered on a particular detector in two different worlds. In no single world is more than one value measured for any of the particles.

Explicitly, the first factor in PE, depite its notation '$r_{Bi}(\hat{\lambda}_a)$', corresponds to the measured A-spin in a d-world (ie. a world where detector orientations are $d= (\theta_A'', \theta_B'')$) which we know, by three of the above equations, must equal the measured B-spin in an a-world. Similarly the second factor corresponds to the measured B-spin in a d-world which, by one of the above locality conditions, equals the measured B-spin in a b-world. So PE is really the product of the measured A and B-spins in a d-world (which is unproblematic) with the individual factors equalling the measured B-spins in two other distinct (a and b-)worlds. None of this requires there to be B-spin measurements along two distinct axes in the same world! Ofcourse Fellows' is correct in stating that "...a comparison with the quantum theory must be based on physical measurements, not on conceivable groupings of numbers." implying that PE must be an expression referring to a product of measured spins in a single world in order to be legitimately compared to QM's predictions. However Fellows' troubles begin when he mistakes this to be a world in which the B-spin is measured along two distinct directions rather than the aforementioned d-world.

Now as Stapp points out what is wrong with CC1 is its use of would as opposed to could since the former presupposes determinism. (For example, in CC2 would is inappropriate if the situation considered involves a light switch connected to a machine which flips a(n indeterministic) coin to decide whether or not the light should go on.) In fact he argues[5] that in his original proof he never presupposed a would but rather a could interpretation of his locality conditions. I am skeptical about this claim for two reasons. First the word would (not could, which never appears) occurs in his own formulation of these conditions[2], and even though he says these conditions are imposed "not on what does happen, but only on the possibilities"[5] such an assertion is still consistent with a would interpretation (ie. a would counterfactual conditional, like CC1, makes an assertion about conceivable possibilities just as much as a could version of CC1 does). Secondly, if interpreted in the could sense his locality conditions do not contradict QM predictions! To see this consider the two could versions of CC1 for the $i^{th}$ and $i+1^{th}$ particle pair. It is well known from the logical theory of counterfactuals that these two could conditionals do not (at world w) jointly imply the conditional 'If the distant B-detector had been set to $\theta_B''$, then the A-measurement could have

yielded $r_{Ai}(\hat{\lambda}_b)$ and $r_{Ai+1}(\hat{\lambda}_b)$ such that $r_{Ai}(\hat{\lambda}_b) = r_{Ai}(\hat{\lambda}_a)$ and $r_{Ai+1}(\hat{\lambda}_b) = r_{Ai+1}(\hat{\lambda}_a)$ ' with the corresponding conjunctive consequent (note that if would is retained in CC1 this problem does not occur[6]). But to compare his locality conditions with QM's predictions Stapp needs to deduce from these conditions that there will be a state of affairs (or 'world') in which the sequence $r_{A1}(\hat{\lambda}_b)$ and $r_{A2}(\hat{\lambda}_b)$ and ... $r_{An}(\hat{\lambda}_b)$ of A-spins is measured such that for each i, $r_{Ai}(\hat{\lambda}_b) = r_{Ai}(\hat{\lambda}_a)$, because QM only gives predictions for the statistics of sequences of measurement outcomes in worlds governed by QM's laws. Logically such a world cannot be deduced given a could interpretation![7]

In any case, the could vs. would issue does nothing to neutralize Fellows' two objections above concerning the simultaneous measurement of two noncommuting spin observables in a single world[8]. (Also Fellows feels his criticisms undercut both would and could versions of the proof - see below.) Now neither of these objections so far expose in the proof any assumption of physical realism which is a thesis about the existence of physical quantities apart from their measurement. Nevertheless Fellows believes "Stapp's locality conditions do include a realistic element, so it should come as no surprise that they fail to accord with the quantum theory." For regardless of whether would or could is used[9], "To compare deductions about quartets of spin components...with the quantum theory means assuming the simultaneous existence of the four members of the quartet; two of these members represent the outcomes of experiments that cannot be performed, and hence show the presence of realism in the argument." Since we saw earlier that in no single world are two spin measurements performed on the same particle, Fellows is wrong in accusing Stapp of assuming physical realism (which concerns the independent existence of physical quantities in the actual world)[10] for the "realistic element" with which Fellows is now concerned is what philosophers call modal realism, that is, the thesis that events, in this case measurement outcomes, which do not occur in the actual world but are merely imagined or conceived to occur really do (in some sense) exist. For example, Fellows seems to be saying that when a conditional like CC2 is asserted in the actual world in which the light is off, this assertion commits us to the existence of a shining light, despite its nonexistence in the actual world. But although at least one eminent philosopher of science[11] holds that this view provides ~~the best~~ a good way to make sense out of our modal reasoning, noone believes ~~we are thereby~~ such reasoning inevitably commit~~ted~~s us to the real existence of unactualized possible 'worlds' (which would be a somewhat incredible view!) beyond
#2 using them purely as a device for the logical/semantical analysis of language. Thus Stapp's proof assumes no more than the real existence of measured spin values registering on macroscopic detectors in exactly one world - the actual world (which ever world - ie. either an a, b, c, or d-world - that happens to be).

[1]F. Fellows, Am. J. Phys. **56**, 567 (1988)

[2]H. P. Stapp, Am. J. Phys. **53**, 306 (1985)

[3]H. P. Stapp, Am. J. Phys. **56**, 568 (1988)

[4]Some critics of Bell's theorem reject its use of counterfactual reasoning per se. For them,

imagining these 'possible worlds' different (re:detector settings) from the way things actually are takes us away from the real world with which we should be concerned and to which it alone physics applies. But even the most anti-realist philosophers of science concede that counterfactuals form an indispensible part of logical reasoning in science. Further, if the 'possible worlds' with which we are concerned did not also have actual physical laws governing the phenomena in them, we would have to entertain the unacceptable view that actually observed laws of nature are somehow causally dependent on the particular settings of the detectors.

[5]In note 3 (final paragraph) and H. P. Stapp, Am. J. Phys. **56**, 567 (1988) (paragraph 5)

[6]D. Lewis, Counterfactuals (Blackwell Press,Oxford, 1973) p.21

[7]In Stapp's post-1985 proofs, for example in his article "Quantum Nonlocality and the Description of Nature" to appear in Philosophical Lessons from Quantum Theory, edited by E. McMullin and J. T. Cushing. (Notre Dame University Press, Notre Dame, 1989), the locality conditions are revised in such a way that this problem does not arise. But this new proof has its own problems (cf. section 3 of R. K. Clifton, J. N. Butterfield, and M. L. G. Redhead "Nonlocal Influences and Possible Worlds - A Stapp in the Wrong Direction", forthcoming article (1989)) chiefly that it is logically invalid. So I agree with Stapp (note 3) that the issues are "purely logical and theoretical ones" however they are not ultimately resolved in his favour.

[8]The closest Stapp comes to giving a satisfactory reply to Fellows is to his statement that "The quantum theory will not support the distinction between what would happen and what could happen in an experiment". But Stapp's reply includes stating that the completeness of quantum theory depends upon the availability of this distinction. However, without presupossing completeness, one need only reply that this distinction exists in the logic of natural language and therefore cannot be falsified by, or incompatible with, a physical theory (unless one takes the view of quantum logicians who believe physical theories can provide grounds upon which to revise logic itself).

[9]At this stage Fellows is referring, in addition to the reference in note 2, to the "more abstract" could version of the proof found in H. P. Stapp, Found. Phys. **18**, 427 (1988) which can also be found in other articles (eg. see note 7).

[10]Even the (rather unjustified) assumption of determinism needed for substantiating a would version of the proof need not involve physical realism. For determinism can be construed pragmatically as the belief that the joint state of the particle plus measurement device after measurement is uniquely predictable from the mathematical formalism of a "more complete" theory than QM without at any time committing oneself to the actual physical existence of entities beyond the formalism and the macroscopic world.

[11]D. Lewis, On the Plurality of Worlds (Blackwell Press, Oxford,1986)